CHAPTER 1

WAVE PROPAGATION

The eyes and ears of a ship or shore station depend on sophisticated, highly computerized electronic systems. The one thing all of these systems have in common is that they lead to and from *antennas.* Ship's operators who must communicate, navigate, and be ready to fight the ship 24 hours a day depend on you to keep these emitters and sensors operational.

In this volume, we will review wave propagation, antenna characteristics, shore-based and shipboard communications antennas, matching networks, antenna tuning, radar antennas, antenna safety, transmission lines, connector installation and weatherproofing, waveguides, and waveguide couplings. When you have completed this chapter, you should be able to discuss the basic principles of wave propagation and the atmosphere's effects on wave propagation.

THE EARTH'S ATMOSPHERE

While radio waves traveling in free space have little outside influence to affect them, radio waves traveling in the earth's atmosphere have many influences that affect them. We have all experienced problems with radio waves, caused by certain atmospheric conditions complicating what at first seemed to be a relatively simple electronic problem. These problem-causing conditions result from a lack of uniformity in the earth's atmosphere.

Many factors can affect atmospheric conditions, either positively or negatively. Three of these are variations in geographic height, differences in geographic location, and changes in time (day, night, season, year).

To understand wave propagation, you must have at least a basic understanding of the earth's atmosphere. The earth's atmosphere is divided into three separate regions, or layers. They are the *troposphere,* the *stratosphere,* and the *ionosphere.* These layers are illustrated in figure 1-1.

TROPOSPHERE

Almost all weather phenomena take place in the troposphere. The temperature in this region decreases rapidly with altitude. Clouds form, and there may be a lot of turbulence because of variations in the temperature, pressure, and density. These conditions have a profound effect on the propagation of radio waves, as we will explain later in this chapter.

STRATOSPHERE

The stratosphere is located between the troposphere and the ionosphere. The temperature throughout this region is almost constant and there is little water vapor present. Because it is a relatively calm region with little or no temperature change, the stratosphere has almost no effect on radio waves.

IONOSPHERE

This is the most important region of the earth's atmosphere for long distance, point-to-point communications. Because the existence of the ionosphere is directly related to radiation emitted from the sun, the movement of the earth about the sun or changes in the sun's activity will result in variations in the ionosphere. These variations are of two general types: (1) those that more or less occur in cycles and, therefore, can be predicted with reasonable accuracy; and (2) those that are irregular as a result of abnormal behavior of the sun and, therefore, cannot be predicted. Both regular and irregular variations have important effects on radio-wave propagation. Since irregular variations cannot be predicted, we will concentrate on regular variations.

Regular Variations

The regular variations can be divided into four main classes: daily, 27-day, seasonal, and 11-year. We will concentrate our discussion on daily variations,

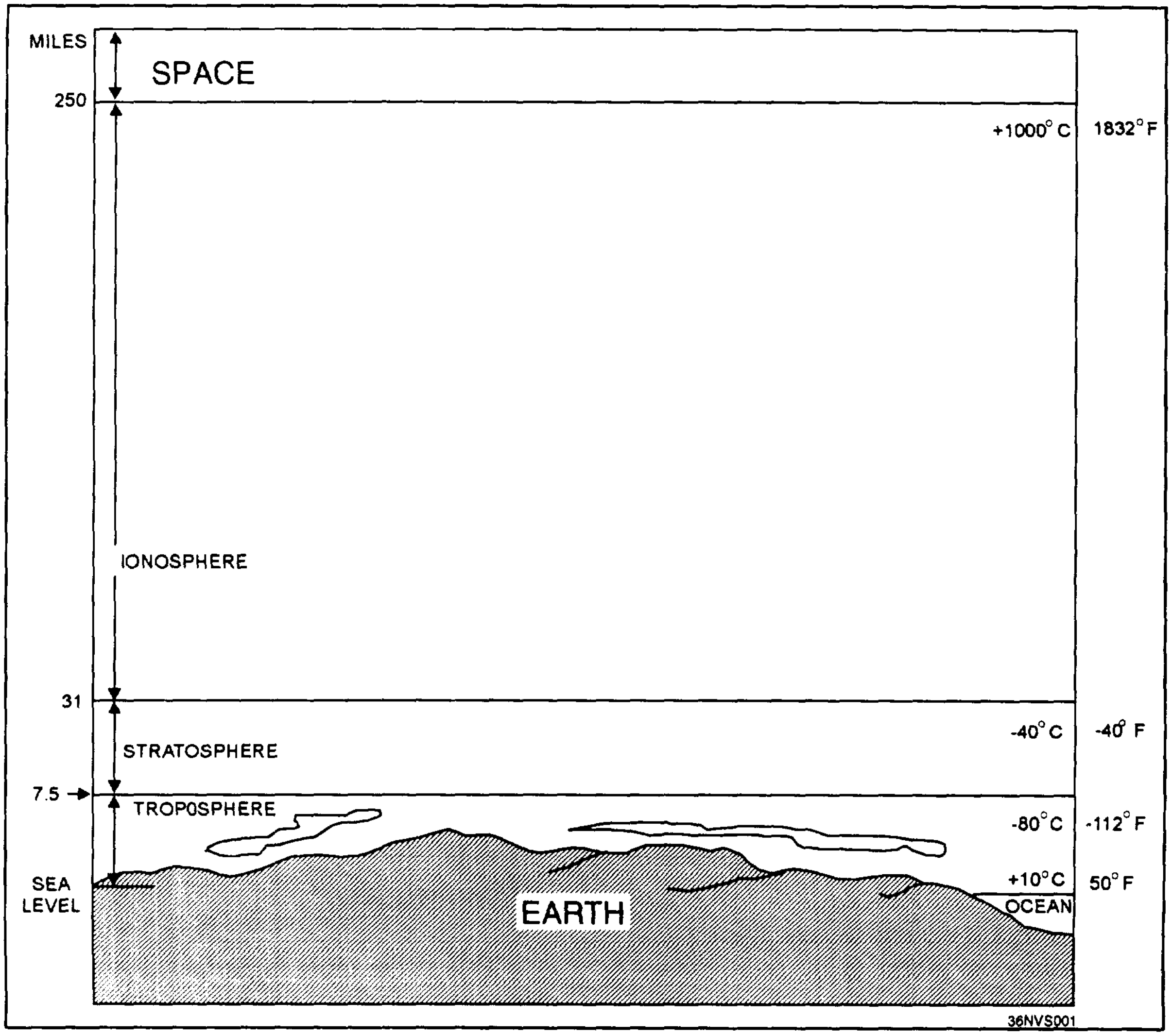


Figure 1.1—Atmospheric layers.

since they have the greatest effect on your job. Daily variations in the ionosphere produce four cloud-like layers of electrically-charged gas atoms called *ions*, which enable radio waves to be propagated great distances around the earth. Ions are formed by a process called *ionization*.

Ionization

In ionization, high-energy ultraviolet light waves from the sun periodically enter the ionosphere, strike neutral gas atoms, and knock one or more electrons free from each atom. When the electrons are knocked free, the atoms become positively charged **(positive ions)** and remain in space, along with the negatively-charged free electrons. The free electrons absorb some of the ultraviolet energy that initially set them free and form an ionized layer.

Since the atmosphere is bombarded by ultraviolet waves of differing frequencies, several ionized layers are formed at different altitudes. Ultraviolet waves of higher frequencies penetrate the most, so they produce ionized layers in the lower portion of the ionosphere. Conversely, ultraviolet waves of lower frequencies penetrate the least, so they form layers in the upper regions of the ionosphere.

An important factor in determining the density of these ionized layers is the elevation angle of the sun. Since this angle changes frequently, the height and thickness of the ionized layers vary, depending on the time of day and the season of the year. Another important factor in determining layer density is known as *recombination*.

Recombination

Recombination is the reverse process of ionization. It occurs when free electrons and positive ions collide, combine, and return the positive ions to their original neutral state.

Like ionization, the recombination process depends on the time of day. Between early morning and late afternoon, the rate of ionization exceeds the rate of recombination. During this period the ionized layers reach their greatest density and exert maximum influence on radio waves. However, during the late afternoon and early evening, the rate of recombination exceeds the rate of ionization, causing the densities of the ionized layers to decrease. Throughout the night, density continues to decrease, reaching its lowest point just before sunrise. It is important to understand that this ionization and recombination process varies, depending on the ionospheric layer and the time of day. The following paragraphs provide an explanation of the four ionospheric layers.

Ionospheric Layers

The ionosphere is composed of three distinct layers, designated from lowest level to highest level **(D, E,** and **F)** as shown in figure 1-2. In addition, the **F** layer is divided into two layers, designated **F1** (the lower level) and **F2** (the higher level).

The presence or absence of these layers in the ionosphere and their height above the earth vary with the position of the sun. At high noon, radiation in the ionosphere above a given point is greatest, while at night it is minimum. When the radiation is removed, many of the particles that were ionized recombine. During the time between these two conditions, the position and number of ionized layers within the ionosphere change.

Since the position of the sun varies daily, monthly, and yearly with respect to a specific point on earth, the exact number of layers present is extremely difficult to determine. However, the following general statements about these layers can be made.

D LAYER.— The **D** layer ranges from about 30 to 55 miles above the earth. Ionization in the **D** layer is low because less ultraviolet light penetrates to this level. At very low frequencies, the **D** layer and the ground act as a huge waveguide, making communication possible only with large antennas and high-power transmitters. At low and medium frequencies, the **D** layer becomes highly absorptive, which limits the effective daytime communication range to about 200 miles. At frequencies above about 3 MHz, the **D** layer begins to lose its absorptive qualities.

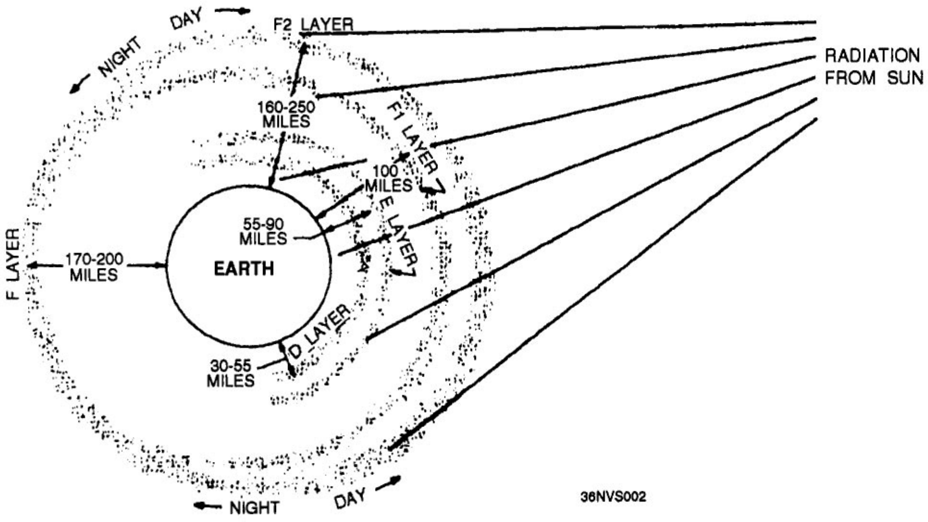


Figure 1-2.—Layers of the ionosphere.

Long-distance communication is possible at frequencies as high as 30 MHz. Waves at frequencies above this range pass through the **D** layer but are attenuated. After sunset. the **D** layer disappears because of the rapid recombination of ions. Low-frequency and medium-frequency long-distance communication becomes possible. This is why **AM** behaves so differently at night. Signals passing through the **D** layer normally are not absorbed but are propagated by the **E** and **F** layers.

E LAYER.— The **E** layer ranges from approximately 55 to 90 miles above the earth. The rate of ionospheric recombination in this layer is rather rapid after sunset, causing it to nearly disappear by midnight. The **E** layer permits medium-range communications on the low-frequency through very-high-frequency bands. At frequencies above about 150 MHz, radio waves pass through the **E** layer.

Sometimes a solar flare will cause this layer to ionize at night over specific areas. Propagation in this layer during this time is called SPORADIC-E. The range of communication in sporadic-E often exceeds 1000 miles, but the range is not as great as with F layer propagation.

F LAYER.— The **F** layer exists from about 90 to 240 miles above the earth. During daylight hours, the **F** layer separates into two layers, **F1** and **F2.** During the night, the **F1** layer usually disappears, The **F** layer produces maximum ionization during the afternoon hours, but the effects of the daily cycle are not as pronounced as in the **D** and **E** layers. Atoms in the **F** layer stay ionized for a longer time after sunset, and during maximum sunspot activity, they can stay ionized all night long.

Since the **F** layer is the highest of the ionospheric layers, it also has the longest propagation capability. For horizontal waves, the single-hop **F2** distance can reach 3000 miles. For signals to propagate over greater distances, multiple hops are required.

The **F** layer is responsible for most high-frequency, long-distance communications. The maximum frequency that the **F** layer will return depends on the degree of sunspot activity. During maximum sunspot activity, the **F** layer can return signals at frequencies as high as 100 MHz. During minimum sunspot activity, the maximum usable frequency can drop to as low as 10 MHz.

ATMOSPHERIC PROPAGATION

Within the atmosphere, radio waves can be refracted, reflected, and diffracted. In the following paragraphs, we will discuss these propagation characteristics.

REFRACTION

A radio wave transmitted into ionized layers is always refracted, or bent. This bending of radio waves is called *refraction*. Notice the radio wave shown in figure 1-3, traveling through the earth's atmosphere at a constant speed. As the wave enters the denser layer of charged ions, its upper portion moves faster than its lower portion. The abrupt speed increase of the upper part of the wave causes it to bend back toward the earth. This bending is always toward the propagation medium where the radio wave's velocity is the least.

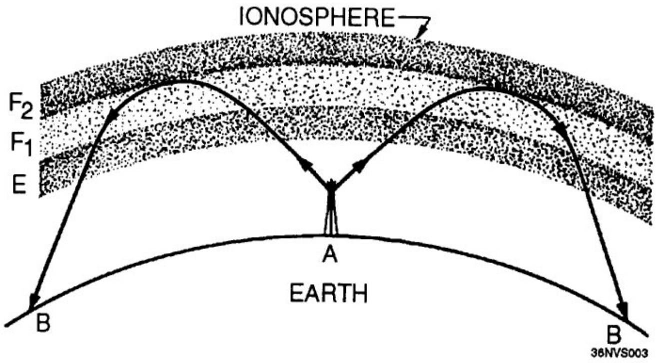


Figure 1-3.—Radio-wave refraction.

The amount of refraction a radio wave undergoes depends on three main factors.

1. The ionization density of the layer

2. The frequency of the radio wave

3. The angle at which the radio wave enters the layer

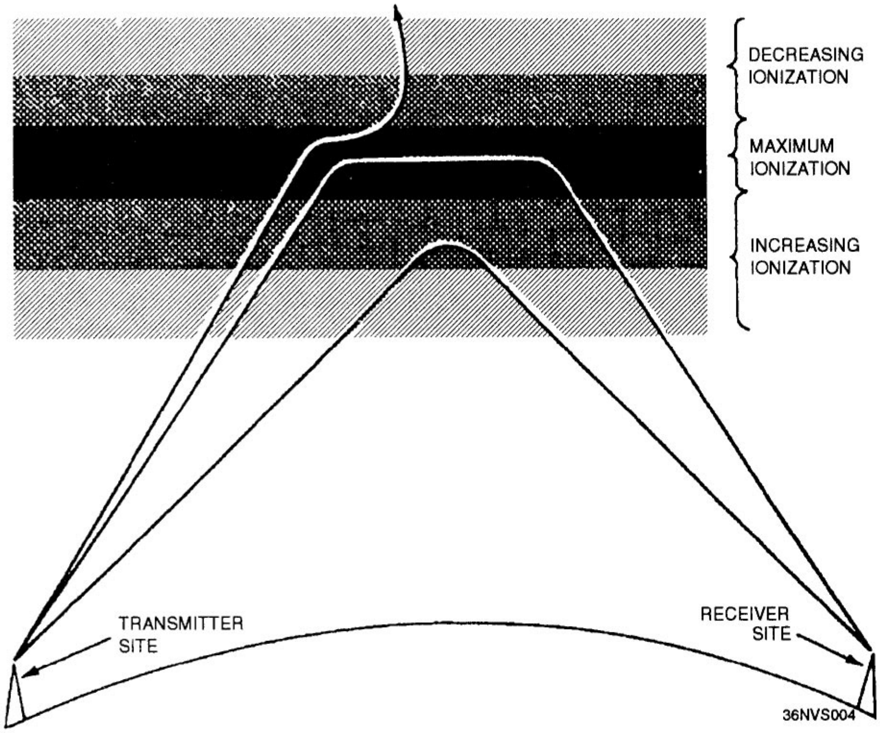


Figure 1-4.—Effects of ionospheric density on radio waves.

Layer Density

Figure 1-4 shows the relationship between radio waves and ionization density. Each ionized layer has a middle region of relatively dense ionization with less intensity above and below. As a radio wave enters a region of **increasing** ionization, a velocity increase causes it to bend back **toward** the earth. In the highly dense middle region, refraction occurs more slowly because the ionization density is uniform. As the wave enters the upper less dense region, the velocity of the upper part of the wave decreases and the wave is bent away from the earth.

Frequency

The lower the frequency of a radio wave, the more rapidly the wave is refracted by a given degree of ionization. Figure 1-5 shows three separate waves of differing frequencies entering the ionosphere at the same angle. You can see that the 5-MHz wave is refracted quite sharply, while the 20-MHz wave is refracted less sharply and returns to earth at a greater distance than the 5-MHz wave. Notice that the 100-MHz wave is lost into space. For any given ionized layer, there is a frequency, called the *escape point*, at which energy transmitted directly upward will escape into space. The maximum frequency just below the escape point is called the **critical frequency.** In this example, the 100-MHz wave's frequency is greater than the critical frequency for that ionized layer.

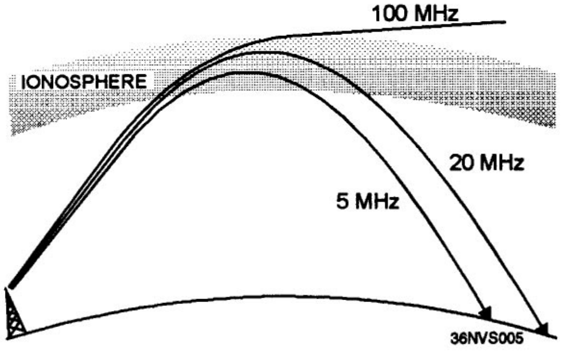


Figure 1-5.—Frequency versus refraction and distance.

The critical frequency of a layer depends upon the layer's density. If a wave passes through a particular layer, it may still be refracted by a higher layer if its frequency is lower than the higher layer's critical frequency.

Angle of Incidence and Critical Angle

When a radio wave encounters a layer of the ionosphere, that wave is returned to earth at the same angle (roughly) as its *angle of incidence.* Figure 1-6 shows three radio waves of the same frequency entering a layer at different incidence angles. The angle at which wave A strikes the layer is too nearly vertical for the wave to be refracted to earth, However, wave B is refracted back to earth. The angle between wave B and the earth is called the **critical angle.** Any wave, at a given frequency, that leaves the antenna at an incidence angle greater than the critical angle will be lost into space. This is why wave A was not refracted. Wave C leaves the antenna at the smallest angle that will allow it to be refracted and still return to earth. The critical angle for radio waves depends on the layer density and the wavelength of the signal.

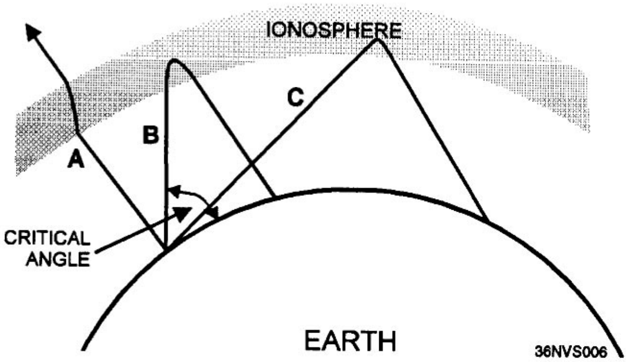


Figure 1-6.—Incidence angles of radio waves.

As the frequency of a radio wave is increased, the critical angle must be reduced for refraction to occur. Notice in figure 1-7 that the 2-MHz wave strikes the ionosphere at the critical angle for that frequency and is refracted. Although the 5-MHz line (broken line) strikes the ionosphere at a less critical angle, it still penetrates the layer and is lost As the angle is lowered, a critical angle is finally reached for the 5-MHz wave and it is refracted back to earth.

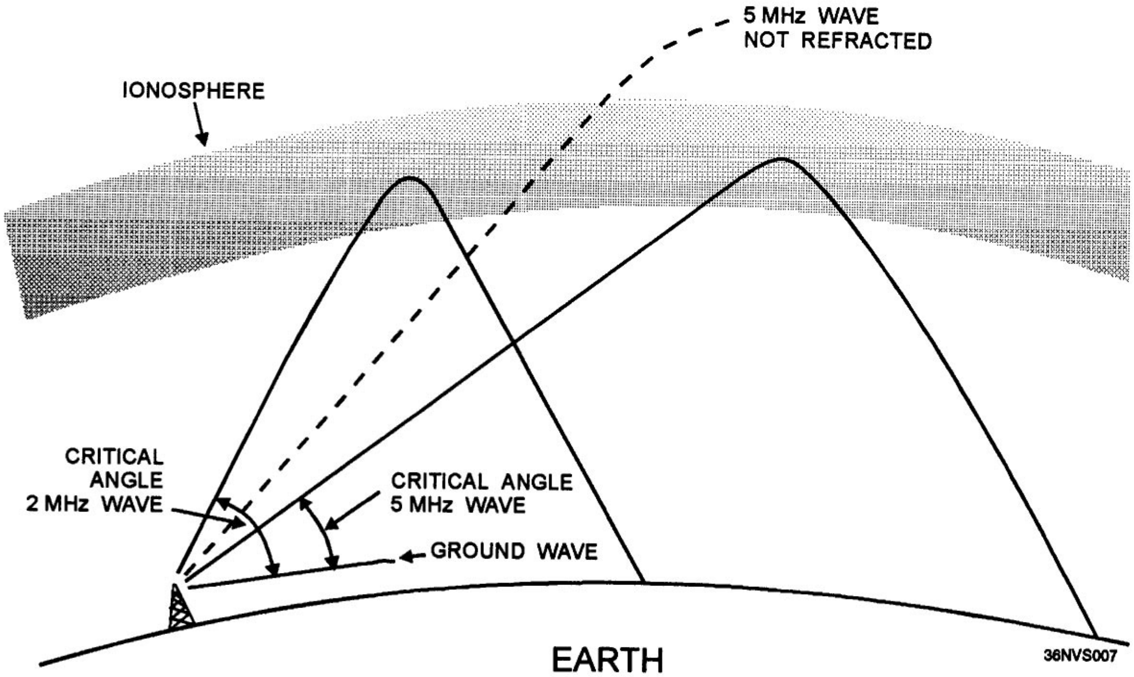


Figure 1-7.—Effect of frequency on the critical angle.

SKIP DISTANCE AND ZONE

Recall from your previous study that a transmitted radio wave separates into two parts, the sky wave and the ground wave. With those two components in mind, we will now briefly discuss *skip distance* and *skip zone.*

Skip Distance

Look at the relationship between the sky wave skip distance, skip zone, and ground wave coverage shown in figure 1-8. The *skip distance* is the distance from the transmitter to the point where the sky wave first returns to the earth. The skip distance depends on the wave's frequency and angle of incidence, and the degree of ionization.

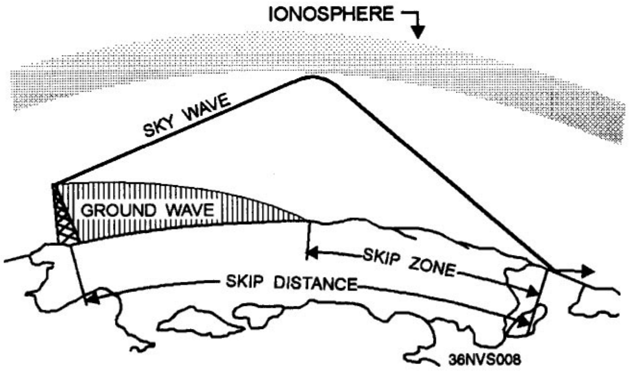


Figure 1-8.—Relationship between skip zone, skip distance, and ground wave.

Skip Zone

The *skip zone* is a zone of silence between the point where the ground wave is too weak for reception and the point where the sky wave is first returned to earth. The outer limit of the skip zone varies considerably, depending on the operating frequency, the time of day, the season of the year, sunspot activity, and the direction of transmission.

At very-low, low, and medium frequencies, a skip zone is never present. However, in the high-frequency spectrum, a skip zone is often present. As the operating frequency is increased, the skip zone widens to a point where the outer limit of the skip zone might be several thousand miles away. At frequencies above a certain maximum, the outer limit of the skip zone disappears completely, and no F-layer propagation is possible.

Occasionally, the first sky wave will return to earth within the range of the ground wave. In this case, severe fading can result from the phase difference between the two waves (the sky wave has a longer path to follow).

REFLECTION

Reflection occurs when radio waves are "bounced" from a flat surface. There are basically two types of reflection that occur in the atmosphere: earth reflection and ionospheric reflection. Figure 1-9 shows two

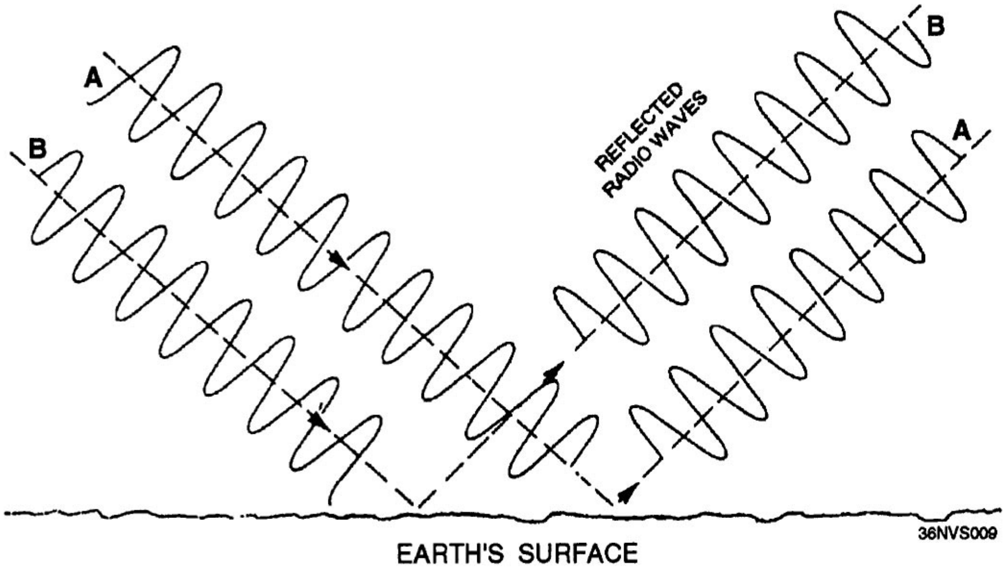


Figure 1-9.—Phase shift of reflected radio waves.

waves reflected from the earth's surface. Waves A and B bounce off the earth's surface like light off of a mirror. Notice that the positive and negative alternations of radio waves A and B are in phase before they strike the earth's surface. However, after reflection the radio waves are approximately 180 degrees out of phase. A phase shift has occurred.

The amount of phase shift that occurs is not constant. It varies, depending on the wave polarization and the angle at which the wave strikes the surface. Because reflection is not constant, fading occurs. Normally, radio waves reflected in phase produce stronger signals, while those reflected out of phase produce a weak or fading signal.

Ionospheric reflection occurs when certain radio waves strike a thin, highly ionized layer in the ionosphere. Although the radio waves are actually refracted, some may be bent back so rapidly that they appear to be reflected. For ionospheric reflection to occur, the highly ionized layer can be approximately no thicker than one wavelength of the wave. Since the ionized layers are often several miles thick, ionospheric reflection mostly occurs at long wavelengths (low frequencies).

DIFFRACTION

Diffraction is the ability of radio waves to turn sharp corners and bend around obstacles. Shown in figure 1-10, diffraction results in a change of direction of part of the radio-wave energy around the edges of an obstacle. Radio waves with long wavelengths compared to the diameter of an obstruction are easily propagated around the obstruction. However, as the wavelength decreases, the obstruction causes more and more attenuation, until at very-high frequencies a definite *shadow zone* develops. The shadow zone is basically a blank area on the opposite side of an obstruction in line-of-sight from the transmitter to the receiver.

Diffraction can extend the radio range beyond the horizon. By using high power and low-frequencies, radio waves can be made to encircle the earth by diffraction.

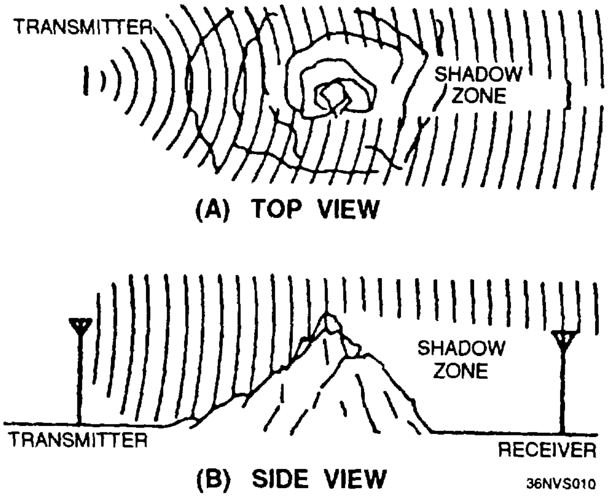


Figure 1-10.—Diffraction around an object.

ATMOSPHERIC EFFECTS ON PROPAGATION

As we stated earlier, changes in the ionosphere can produce dramatic changes in the ability to communicate. In some cases, communications distances are greatly extended. In other cases, communications distances are greatly reduced or eliminated. The paragraphs below explain the major problem of reduced communications because of the phenomena of fading and selective fading.

Fading

The most troublesome and frustrating problem in receiving radio signals is variations in signal strength, most commonly known as FADING. Several conditions can produce fading. When a radio wave is refracted by the ionosphere or reflected from the earth's surface, random changes in the polarization of the wave may occur. Vertically and horizontally mounted receiving antennas are designed to receive vertically and horizontally polarized waves, respectively. Therefore, changes in polarization cause changes in the received signal level because of the inability of the antenna to receive polarization changes.

Fading also results from absorption of the rf energy in the ionosphere. Most ionospheric absorption occurs in the lower regions of the ionosphere where ionization density is the greatest. As a radio wave passes into the ionosphere, it loses some of its energy to the free electrons and ions present there. Since the amount of absorption of the radio-wave energy varies with the density of the ionospheric layers, there is no fixed relationship between distance and signal strength for ionospheric propagation. Absorption fading occurs for a longer period than other types of fading, since absorption takes place slowly. Under certain conditions, the absorption of energy is so great that communication over any distance beyond the line of sight becomes difficult.

Although fading because of absorption is the most serious type of fading, fading on the ionospheric circuits is mainly a result of multipath propagation.

Multipath Fading

MULTIPATH is simply a term used to describe the multiple paths a radio wave may follow between transmitter and receiver. Such propagation paths include the ground wave, ionospheric refraction, reradiation by the ionospheric layers, reflection from the earth's surface or from more than one ionospheric layer, and so on. Figure 1-11 shows a few of the paths that a signal can travel between two sites in a typical circuit. One path, XYZ, is the basic ground wave. Another path, XFZ, refracts the wave at the F layer and passes it on to the receiver at point Z. At point Z, the received signal is a combination of the ground wave and the sky wave. These two signals, having traveled different paths, arrive at point Z at different times. Thus, the arriving waves may or may not be in phase with each other. A similar situation may result at point A. Another path, XFZFA, results from a greater angle of incidence and two refractions from the F layer. A wave traveling that path and one traveling the XEA path may or may not arrive at point A in phase. Radio waves that are received in phase reinforce each other and produce a stronger signal at the receiving site, while those that are received out of phase produce a weak or fading signal. Small alterations in the transmission path may change the phase relationship of the two signals, causing periodic fading.

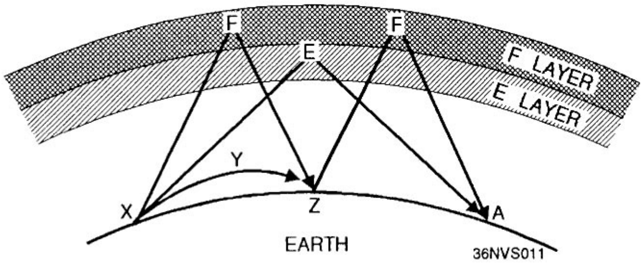


Figure 1-11.—Multipath transmission.

Multipath fading may be minimized by practices called SPACE DIVERSITY and FREQUENCY DIVERSITY In space diversity, two or more receiving antennas are spaced some distance apart. Fading does not occur simultaneously at both antennas. Therefore, enough output is almost always available from one of the antennas to provide a useful signal.

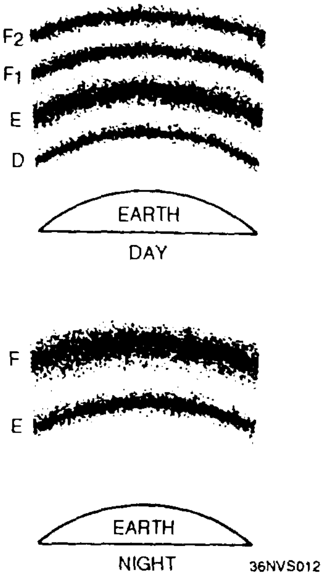
In frequency diversity, two transmitters and two receivers are used, each pair tuned to a different frequency, with the same information being transmitted simultaneously over both frequencies. One of the two receivers will almost always produce a useful signal.

Selective Fading

Fading resulting from multipath propagation varies with frequency since each frequency arrives at the receiving point via a different radio path. When a wide band of frequencies is transmitted simultaneously, each frequency will vary in the amount of fading. This variation is called SELECTIVE FADING. When selective fading occurs, all frequencies of the transmitted signal do not retain their original phases and relative amplitudes. This fading causes severe distortion of the signal and limits the total signal transmitted.

Frequency shifts and distance changes because of daily variations of the different ionospheric layers are summarized in table 1-1.

Table 1-1.–Daily Ionospheric Communications

D LAYER: reflects vlf waves for long-range communications; refracts lf and mf for short-range communications; has little effect on vhf and above; gone at night.	 Figure 1-12.—Ionospheric layers.
E LAYER: depends on the angle of the sun: refracts hf waves during the day up to 20 MHz to distances of 1200 miles: greatly reduced at night.	
F LAYER: structure and density depend on the time of day and the angle of the sun: consists of one layer at night and splits into two layers during daylight hours.	
F1 LAYER: density depends on the angle of the sun; its main effect is to absorb hf waves passing through to the F2 layer.	
F2 LAYER: provides long-range hf communications; very variable; height and density change with time of day, season, and sunspot activity.	

OTHER PHENOMENA THAT AFFECT COMMUNICATIONS

Although daily changes in the ionosphere have the greatest effect on communications, other phenomena also affect communications, both positively and negatively. Those phenomena are discussed briefly in the following paragraphs.

SEASONAL VARIATIONS IN THE IONOSPHERE

Seasonal variations are the result of the earth's revolving around the sun, because the relative position of the sun moves from one hemisphere to the other with the changes in seasons. Seasonal variations of the D, E, and F1 layers are directly related to the highest angle of the sun, meaning the ionization density of these layers is greatest during the summer. The F2 layer is just the opposite. Its ionization is greatest during the winter, Therefore, operating frequencies for F2 layer propagation are higher in the winter than in the summer.

SUNSPOTS

One of the most notable occurrences on the surface of the sun is the appearance and disappearance of dark, irregularly shaped areas known as SUNSPOTS. Sunspots are believed to be caused by violent eruptions on the sun and are characterized by strong magnetic fields. These sunspots cause variations in the ionization level of the ionosphere.

Sunspots tend to appear in two cycles, every 27 days and every 11 years.

Twenty-Seven Day Cycle

The number of sunspots present at any one time is constantly changing as some disappear and new ones emerge. As the sun rotates on its own axis, these sunspots are visible at 27-day intervals, which is the approximate period for the sun to make one complete revolution. During this time period, the fluctuations in ionization are greatest in the F2 layer. For this reason, calculating critical frequencies for long-distance communications for the F2 layer is not possible and allowances for fluctuations must be made.

Eleven-Year Cycle

Sunspots can occur unexpectedly, and the life span of individual sunspots is variable. The ELEVEN-YEAR SUN SPOT CYCLE is a regular cycle of sunspot activity that has a minimum and maximum level of activity that occurs every 11 years. During periods of maximum activity, the ionization density of all the layers increases. Because of this, the absorption in the D layer increases and the critical frequencies for the E, F1, and F2 layers are higher. During these times, higher operating frequencies must be used for long-range communications.

IRREGULAR VARIATIONS

Irregular variations are just that, unpredictable changes in the ionosphere that can drastically affect our ability to communicate. The more common variations are sporadic E, ionospheric disturbances, and ionospheric storms.

Sporadic E

Irregular cloud-like patches of unusually high ionization, called the sporadic E, often format heights near the normal E layer. Their exact cause is not known and their occurrence cannot be predicted. However, sporadic E is known to vary significantly with latitude. In the northern latitudes, it appears to be closely related to the aurora borealis or northern lights.

The sporadic E layer can be so thin that radio waves penetrate it easily and are returned to earth by the upper layers, or it can be heavily ionized and extend up to several hundred miles into the ionosphere. This condition may be either harmful or helpful to radio-wave propagation.

On the harmful side, sporadic E may blank out the use of higher more favorable layers or cause additional absorption of radio waves at some frequencies. It can also cause additional multipath problems and delay the arrival times of the rays of RF energy.

On the helpful side, the critical frequency of the sporadic E can be greater than double the critical frequency of the normal ionospheric layers. This may permit long-distance communications with unusually high frequencies. It may also permit short-distance communications to locations that would normally be in the skip zone.

Sporadic E can appear and disappear in a short time during the day or night and usually does not occur at same time for all transmitting or receiving stations.

Sudden Ionospheric Disturbances

Commonly known as SID, these disturbances may occur without warning and may last for a few minutes to several hours. When SID occurs, long-range hf communications are almost totally blanked out. The radio operator listening during this time will believe his or her receiver has gone dead.

The occurrence of SID is caused by a bright solar eruption producing an unusually intense burst of ultraviolet light that is not absorbed by the F1, F2, or E layers. Instead, it causes the D-layer ionization density to greatly increase. As a result, frequencies above 1 or 2 megahertz are unable to penetrate the D layer and are completely absorbed.

Ionospheric Storms

Ionospheric storms are caused by disturbances in the earth’s magnetic field. They are associated with both solar eruptions and the 27-day cycle, meaning they are related to the rotation of the sun. The effects of ionospheric storms are a turbulent ionosphere and very erratic sky-wave propagation. The storms affect mostly the F2 layer, reducing its ion density and causing the critical frequencies to be lower than normal. What this means for communication purposes is that the range of frequencies on a given circuit is smaller than normal and that communications are possible only at lower working frequencies.

Weather

Wind, air temperature, and water content of the atmosphere can combine either to extend radio communications or to greatly attenuate wave propagation. making normal communications extremely difficult. Precipitation in the atmosphere has its greatest effect on the higher frequency ranges. Frequencies in the hf range and below show little effect from this condition.

RAIN.— Attenuation because of raindrops is greater than attenuation for any other form of precipitation. Raindrop attenuation may be caused either by absorption, where the raindrop acts as a poor dielectric, absorbs power from the radio wave and dissipates the power by heat loss; or by scattering (fig. 1-13). Raindrops cause greater attenuation by scattering than by absorption at frequencies above 100 megahertz. At frequencies above 6 gigahertz, attenuation by raindrop scatter is even greater.

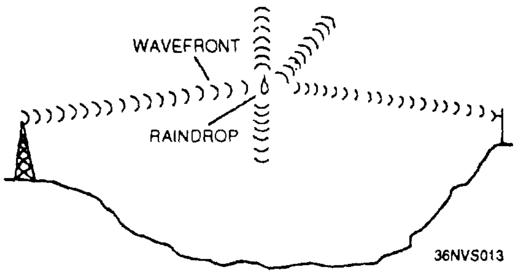


Figure 1-13.–Rf energy losses from scattering.

FOG.— Since fog remains suspended in the atmosphere, the attenuation is determined by the quantity of water per unit volume (density of the fog) and by the size of the droplets. Attenuation because of fog has little effect on frequencies lower than 2 gigahertz, but can cause serious attenuation by absorption at frequencies above 2 gigahertz.

SNOW.— Since snow has about 1/8 the density of rain, and because of the irregular shape of the snowflake, the scattering and absorption losses are difficult to compute, but will be less than those caused by raindrops.

HAIL.— Attenuation by hail is determined by the size of the stones and their density. Attenuation of radio waves by scattering because of hailstones is considerably less than by rain.

TEMPERATURE INVERSION

When layers of warm air form above layers of cold air, the condition known as temperature inversion develops. This phenomenon causes ducts or channels to be formed, by sandwiching cool air either between the surface of the earth and a layer of warm air, or between two layers of warm air. If a transmitting antenna extends into such a duct, or if the radio wave enters the duct at a very low angle of incidence, vhf and uhf transmissions may be propagated far beyond normal line-of-sight distances. These long distances are possible because of the different densities and refractive qualities of warm and cool air. The sudden change in densities when a radio wave enters the warm air above the duct causes the wave to be refracted back toward earth. When the wave strikes the earth or a warm layer below the duct, it is again reflected or refracted upward and proceeds on through the duct with a multiple-hop type of action. An example of radio-wave propagation by ducting is shown in figure 1-14.

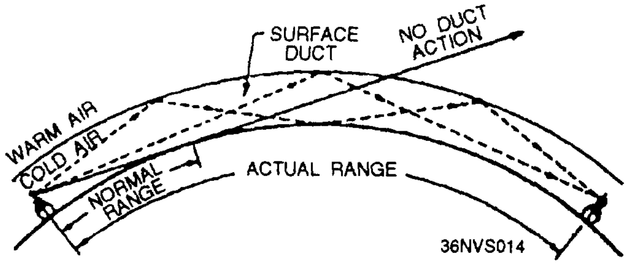


Figure 1-14.—Duct effect caused by temperature inversion.

TRANSMISSION LOSSES

All radio waves propagated over the ionosphere undergo energy losses before arriving at the receiving site. As we discussed earlier, absorption and lower atmospheric levels in the ionosphere account for a large part of these energy losses. There are two other types of losses that also significantly affect propagation. These losses are known as *ground reflection losses* and *freespace loss.* The combined effect of absorption ground reflection loss, and freespace loss account for most of the losses of radio transmissions propagated in the ionosphere.

GROUND REFLECTION LOSS

When propagation is accomplished via multihop refraction, rf energy is lost each time the radio wave is reflected from the earth's surface. The amount of energy lost depends on the frequency of the wave, the angle of incidence, ground irregularities, and the electrical conductivity of the point of reflection.

FREESPACE LOSS

Normally, the major loss of energy is because of the spreading out of the wavefront as it travels from the transmitter. As distance increases, the area of the wavefront spreads out, much like the beam of a flashlight. This means the amount of energy contained within any unit of area on the wavefront decreases as distance increases. By the time the energy arrives at the receiving antenna, the wavefront is so spread out that the receiving antenna extends into only a small portion of the wavefront. This is illustrated in figure 1-15.

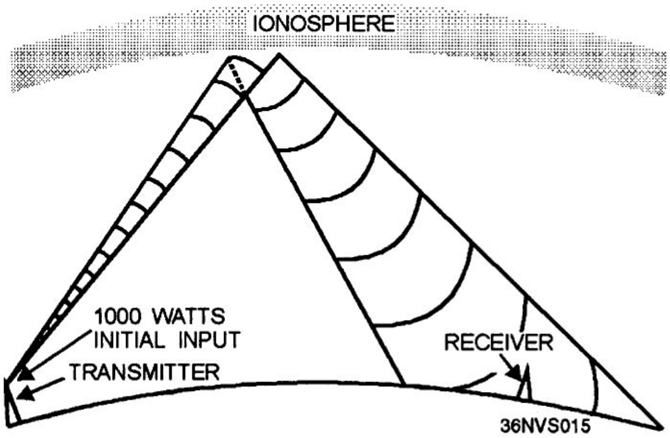


Figure 1-15.—Freespace loss principle.

FREQUENCY SELECTION

You must have a thorough knowledge of radio-wave propagation to exercise good judgment when selecting transmitting and receiving antennas and operating frequencies. Selecting a usable operating frequency within your given allocations and availability is of prime importance to maintaining reliable communications.

For successful communication between <u>any two specified locations</u> at <u>any given time of the day</u>, there is a <u>maximum</u> frequency, a <u>lowes</u>t frequency and an <u>optimum</u> frequency that can be used.

MAXIMUM USABLE FREQUENCY

The higher the frequency of a radio wave, the lower the rate of refraction by the ionosphere. Therefore, for a given angle of incidence and time of day, there is a maximum frequency that can be used for communications between two given locations. This frequency is known as the **MAXIMUM USABLE FREQUENCY** (muf).

Waves at frequencies above the muf are normally refracted so slowly that they return to earth beyond the desired location or pass on through the ionosphere and are lost. Variations in the ionosphere that can raise or lower a predetermined muf may occur at anytime. his is especially true for the highly variable F2 layer.

LOWEST USABLE FREQUENCY

Just as there is a muf that can be used for communications between two points, there is also a minimum operating frequency that can be used known as the LOWEST USABLE FREQUENCY (luf). As the frequency of a radio wave is lowered, the rate of refraction increases. So a wave whose frequency is below the established luf is refracted back to earth at a shorter distance than desired, as shown in figure 1-16.

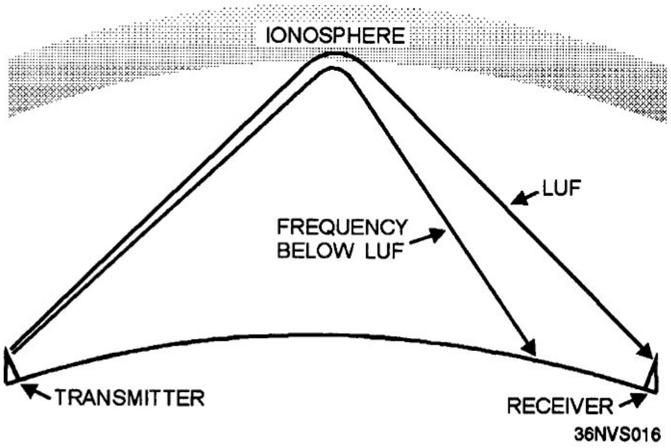


Figure 1-16.—Refraction of frequencies below the lowest usable frequency (luf).

As a frequency is lowered, absorption of the radio wave increases. A wave whose frequency is too low is absorbed to such an extent that it is too weak for reception. Atmospheric noise is also greater at lower frequencies. A combination of higher absorption and atmospheric noise could result in an unacceptable signal-to-noise ratio.

For a given angle ionospheric conditions, of incidence and set of the luf depends on the refraction properties of the ionosphere, absorption considerations, and the amount of noise present.

OPTIMUM WORKING FREQUENCY

The most practical operating frequency is one that you can rely onto have the least number of problems. It should be high enough to avoid the problems of multipath fading, absorption, and noise encountered at the lower frequencies; but not so high as to be affected by the adverse effects of rapid changes in the ionosphere.

A frequency that meets the above criteria is known as the OPTIMUM WORKING FREQUENCY It is abbreviated “fot” from the initial letters of the French words for optimum working frequency, “frequence optimum de travail.” The fot is roughly about 85% of the muf, but the actual percentage varies and may be considerably more or less than 85 percent.

In this chapter, we discussed the basics of radio-wave propagation and how atmospheric conditions determine the operating parameters needed to ensure successful communications. In chapter 2, we will discuss basic antenna operation and design to complete your understanding of radio-wave propagation.